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Measurement of the Mass and Lifetime of the Ξ_c^+

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Measurements of the mass and lifetime of the Ξ_c^+ decaying into $\Xi^-\pi^+\pi^+$ are presented. The data were accumulated by the Fermilab high energy photoproduction experiment E687. The mass of the Ξ_c^+ is measured to be $2464.4 \pm 2.0 \pm 1.4$ MeV/c^2 and the lifetime is measured to be $0.41^{+0.11}_{-0.08} \pm 0.02$ ps.

Theoretical models [1,2] of singly charmed baryon decays can be tested by precision measurements of their lifetimes. However, only the Λ_c^+ lifetime has been measured very accurately [3]. Lifetime measurements of the Ξ_c^+ have been severely statistics limited, and have been measured by only three experiments [4,5,6]. This paper reports a new lifetime measurement of the Ξ_c^+ based on a sample of 29.7 ± 7.0 events decaying into $\Xi^-\pi^+\pi^+$ (references to a specific charge state should be taken to include the charge conjugate state). There are two main competing theoretical models for the lifetimes. Guberina *et al.* [1] predict $\tau(\Omega_c^0) = \tau(\Xi_c^0) < \tau(\Lambda_c^+) < \tau(\Xi_c^+)$, whereas Voloshin and Shifman [2] predict $\tau(\Omega_c^0) < \tau(\Xi_c^0) < \tau(\Lambda_c^+) = \tau(\Xi_c^+)$ (each inequality represents a factor of about 1.5). Both predictions use the c-quark decay spectator model with W-exchange and QCD light quark interference effects.

The data were collected in the Fermilab photoproduction experiment E687 during the 1990-91 run period. Approximately 500 million hadronic triggers were recorded to tape.

The E687 detector, which is described in detail elsewhere [7], is a large aperture spectrometer with good detection capabilities for charged hadrons and photons. The experiment uses a photon beam of mean energy $\sim$ 220 GeV impinging on a Beryllium target. A microvertex detector consisting of 12 planes of silicon microstrips arranged in three views provides high resolution tracking. Deflection of charged particles by two analyzing magnets of opposite polarity is measured by five stations of multiwire proportional chambers (PWCs). Three multicell Čerenkov counters operating in threshold mode are used for particle identification.

The Ξ^-'s are fully reconstructed through the decay channel $\Xi^- \rightarrow \Lambda^0\pi^-$, with the Λ^0 being reconstructed through the $p\pi^-$ decay channel. Decays which occur downstream of the microstrip detectors are reconstructed by intersecting the daughter π^- track and the Λ^0 and by requiring that the direction of the resultant momentum vector agree to within two milliradians with an unmatched microstrip track (the Ξ^- candidate track). In order to remove contamination from $\Omega^- \rightarrow \Lambda^0 K^-$ decays the daughter π^- from the Ξ^- is required to not be identified by the Čerenkov system as being either a definite kaon or kaon/proton ambiguous. Figure 1 shows the $\Lambda^0\pi^-$ invariant mass plot for the decays which occur downstream of the silicon microstrip detectors. Only the downstream decays are used because of the important advantage of having an observed hyperon track in the microstrip detector. This does not significantly reduce the efficiency for reconstructing charmed baryon states since 85% of our Ξ^- signal comes from the downstream decays.

The $\Xi^-\pi^+\pi^+$ combinations are obtained using a candidate-driven vertex finder using the silicon vertex information [7]. The vertex finder works as follows. A secondary vertex is first formed from the Ξ^- silicon track and the two π^+ tracks which are found in both the proportional wire chamber system and the silicon microstrip system. This secondary vertex is required to have a confidence level greater than 1%. Next, a seed track is constructed from the sum of the momentum vectors of the Ξ^- and π^+ tracks. Other tracks consistent with intersecting the seed track are used to form a primary vertex candidate. Finally, the distance L between the primary and secondary vertices is calculated and divided by σ_L, the error on that difference. For most of our analyses the principal cut parameter used to isolate charm signals is the significance of the separation of the primary and secondary vertices, L/σ_L.

The $\Xi^-\pi^+\pi^+$ signal was obtained using the following cuts. Only Ξ^- candidates that have a measured mass within ± 10 MeV/c^2 of the known Ξ^- mass are selected. The Čerenkov system is used to reject candidate π^+ tracks which are identified as definite electrons, kaons or protons.

The secondary vertex is required to lie upstream of a trigger counter located just in front of the first microstrip plane and downstream of the primary vertex. Finally, we cut on the significance of separation of the primary and secondary vertices, the variable L/σ_L. The $\Xi^-\pi^+\pi^+$ signal was studied for a series of separation cuts ranging from $L/\sigma_L > 2$ to $L/\sigma_L > 4.5$. Figure 2 shows the invariant mass distribution for $\Xi^-\pi^+\pi^+$ with an L/σ_L cut of 2.5. The distribution is fitted with a linear background and a Gaussian signal. The fit gives a yield of 29.7 ± 7.0 events at a mass of 2464.4 ± 2.0 MeV/c^2. The measured width of 7.8 MeV/c^2 is in excellent agreement with our experimental resolution. Studies were done to test the possibility of other decays contributing to the $\Xi^-\pi^+\pi^+$ invariant mass distribution. For instance, a $\Lambda_c^+ \to \Xi^- K^+\pi^+$, with the K^+ being misidentified as a π^+, can reflect into the $\Xi^-\pi^+\pi^+$ signal region. The other possibility is a missing π^0, as in the decays $\Xi_c^+ \to \Xi^-\pi^+\pi^+\pi^0$ and $\Xi_c^+ \to \Xi^-\rho^+\pi^+$ (with the ρ^+ decaying to $\pi^+\pi^0$). Monte Carlo studies have shown these contributions to be negligible.

The uncertainty in the mass scale was estimated by comparing the observed masses for the decays $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$, $D^+ \to K^-\pi^+\pi^+$ and $\Lambda_c^+ \to pK^-\pi^+$ with their accepted values [7]. We estimate a systematic uncertainty of ± 1.4 MeV/c^2. The final mass measurement for the Ξ_c^+ is $2464.4 \pm 2.0 \pm 1.4$ MeV/c^2, in good agreement with the current world average of 2466.4 ± 2.1 MeV/c^2 [3].

We use a binned maximum likelihood fit to extract the lifetime. This technique is described in detail in reference [8]. We fit to the reduced proper time (t'), which is defined as $t' = (L - N\sigma_L)/\beta\gamma c$, where N is the significance of vertex detachment cut and $\beta\gamma$ is the Lorentz factor boosting to the Ξ_c^+ center of mass frame. To the extent that σ_L is independent of L (as both Monte Carlo and data studies verify), the t' distribution for Ξ_c^+'s will be of the form $e^{-t'/\tau}$, where τ is the lifetime of the Ξ_c^+.

A fit is made to the t' distribution for events which lie within $\pm 2\sigma$ of the Ξ_c^+ mass, where σ is the measured width of the signal ($\sim$ 8 MeV/c^2). The predicted number of events, n_i, within a reduced proper time bin centered at t'_i is given by

$$n_i = S\frac{f(t'_i)e^{-t'_i/\tau}}{\Sigma f(t'_i)e^{-t'_i/\tau}} + B\frac{b_i}{\Sigma b_i},$$

where $S = N - B$, N is the total number of events in the signal mass region, B is the total number of background events in the signal mass region and b_i is the time evolution of the background as measured from mass sidebands. The function $f(t')$ is a correction function which takes into account the effects of spectrometer acceptance, analysis cut efficiencies and absorption of the daughter particles in the target as a function of the reduced proper time. This function is parametrized as a second order polynomial determined from Monte Carlo studies. We find that the exclusion of $f(t')$ systematically decreases the measured lifetime by 5%.

The background time evolution, b_i, is obtained from events in mass sidebands 10σ wide which are separated from the signal region by 5σ. Both high mass and low mass sidebands are used.

The likelihood is constructed from the Poisson probability of observing s_i events in a reduced proper time bin centered at t'_i, when n_i are predicted. An additional factor, which is the Poisson probability for finding the observed number of events in the background mass sidebands when the expected number is $5B$, is included to tie the value of B to the background level expected from the sidebands. The likelihood, $\mathcal{L}$, takes the form

$$\mathcal{L} = \Pi\,\frac{n_i^{s_i}\,e^{-n_i}}{s_i!} \times \frac{(5B)^{\Sigma b_i}\,e^{-5B}}{(\Sigma b_i)!}.$$

In figure 3 the fit lifetime is plotted versus the significance of separation cut,

L/σ_L. Balancing the need to reduce background systematics while keeping statistical errors small leads us to quote the lifetime at a cut of $L/\sigma_L > 2.5$. At this value of the separation cut the fitted Ξ_c^+ lifetime is $0.41^{+0.11}_{-0.08}$ ps. Figure 4 shows the background subtracted, Monte Carlo corrected, reduced proper time distribution for the Ξ_c^+ signal with the L/σ_L cut used to quote the final lifetime result.

Systematic effects were studied by looking at the variance in the fitted lifetime for different L/σ_L cuts, different fitting methods (a continuous likelihood versus a binned likelihood) and from fitting to the absolute proper time, $L/\beta\gamma c$, (as opposed to the reduced proper time).

The final value for the Ξ_c^+ lifetime is $0.41^{+0.11}_{-0.08}$ (statistical) ± 0.02 (systematic) ps. Our results are compared with the other published results in Table 1.

Table 1. Ξ_c^+ Lifetime Measurements

Experiment	Lifetime (ps)
WA-62	$0.48^{+0.21+0.20}_{-0.15-0.10}$
NA-32	$0.20^{+0.11}_{-0.06}$
E400	$0.40^{+0.18}_{-0.12} \pm 0.10$
E687 (this experiment)	$0.41^{+0.11}_{-0.08} \pm 0.02$

As discussed in the introduction, there are two theoretical models which predict the lifetime hierarchy of the charmed baryons. Guberina *et al.* specifically predict that $\tau(\Xi_c^+) > \tau(\Lambda_c^+)$, whereas Voloshin and Shifman predict $\tau(\Xi_c^+) = \tau(\Lambda_c^+)$. The inequality represents a factor of about 1.5. The authors caution, however, that a large theoretical uncertainty exists. Using the current world average of $0.191^{+0.015}_{-0.012}$ ps for the Λ_c^+ lifetime [3] and the Ξ_c^+ lifetime reported in this paper, one obtains a ratio $\tau(\Xi_c^+)/\tau(\Lambda_c^+) = 2.15 \pm 0.59$.

In summary, we report a mass and lifetime measurement of the charmed strange baryon Ξ_c^+ decaying in the mode $\Xi^-\pi^+\pi^+$, using a precision microvertex detector.

We measure the Ξ_c^+ mass to be $2464.4 \pm 2.0 \pm 1.4$ MeV/c^2 and its lifetime to be $0.41^{+0.11}_{-0.08} \pm 0.02$ ps, from a sample of 29.7 ± 7.0 events.

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Figure Captions

Fig. 1: $\Xi^- \rightarrow \Lambda^0\pi^-$ candidates with decay vertex between the microstrip detectors and the first PWC plane. The yield is 43110 ± 255 events.

Fig. 2: $\Xi^-\pi^+\pi^+$ invariant mass distribution with cuts as described in the text. The significance of detachment cut is $L/\sigma_L > 2.5$.

Fig. 3: Fitted lifetime of the Ξ_c^+ versus the significance of detachment cut, L/σ_L.

Fig. 4: Background subtracted, Monte Carlo corrected, reduced proper time distribution for events in the region $\pm 2\sigma$ around the measured Ξ_c^+ mass. The superimposed curve is a pure exponential using the Ξ_c^+ lifetime found by the fit.

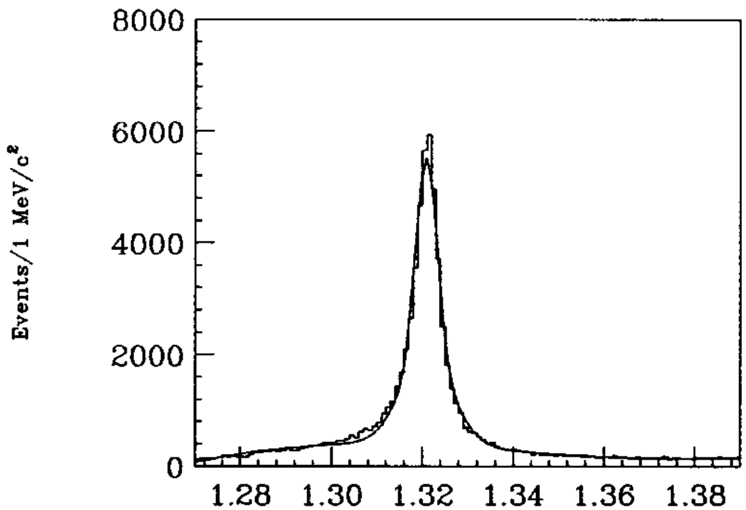

Figure 1. $M(\Lambda^0\pi^-)$ GeV/c^2

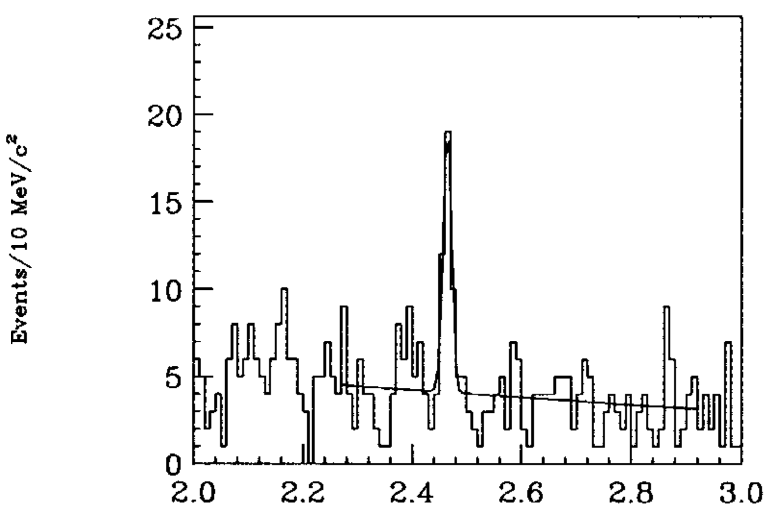

Figure 2. $M(\Xi^-\pi^+\pi^+)$ GeV/c^2

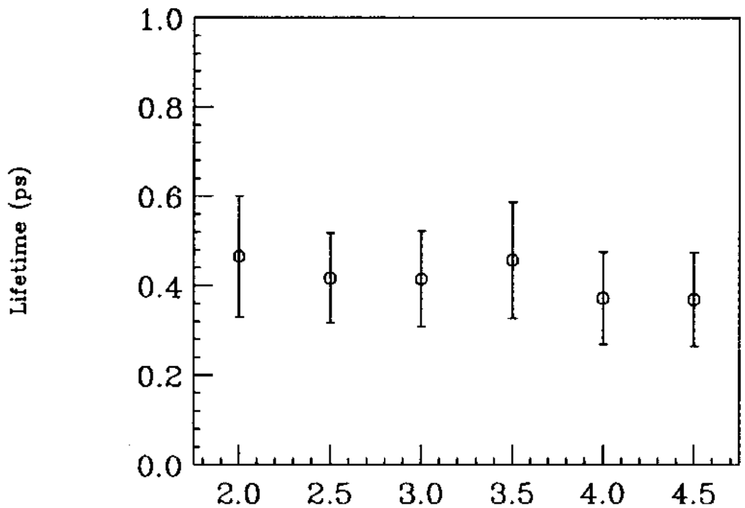

Figure 3. L/σ Cut

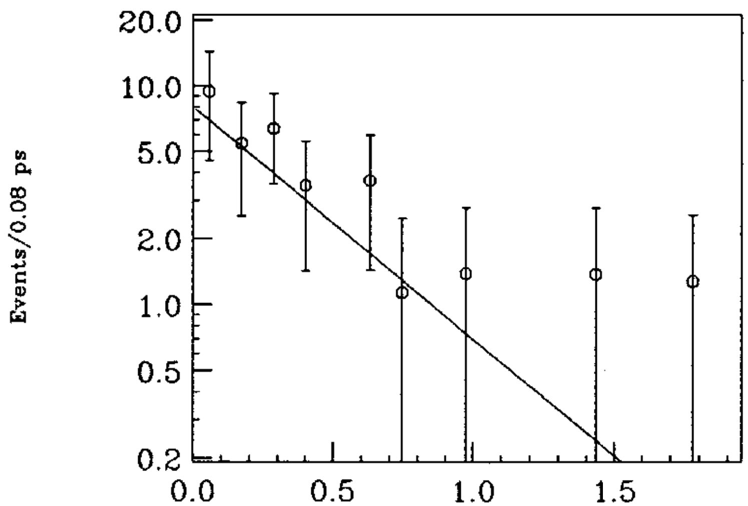

Figure 4. Reduced proper time (ps)